INSECT BEHAVIOR TO VARIOUS WAVE LENGTHS OF LIGHT

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This is the fourth paper, of a series, relating to the group behavior of certain insects to light of various wave-lengths. The first three appeared in this JOURNAL.[1] The present paper is a report of the results of additional tests made in 1942 in the sector type equipment which is fully described in the third paper of the series. As noted previously, in the third paper, the insects were placed in an introduction chamber, six feet away from the filter chambers after the lamps were on and all filter chambers were open. At the ends of the exposure periods the filter chambers, the central compartment, introduction chamber and dark chamber were closed and separated from each other by metal slides. Counts were then made.

In order to determine if the sector type equipment was influencing the behavior of the test insects, by reason of its design, nine white lights of equal intensities (40-watt lamps) were placed at equal distances from clear glass windows and five different tests were made with a total of 1,431 Japanese beetles, for an exposure of 25 minutes. Theoretically, 11.1 per cent of the beetles should have been found in each of the nine compartments. Actually the percentage distribution for the five tests combined was 9, 10, 10, 14, 13, 13, 11, 9, 11, and the average deviation was 1.44 per cent. In view of these results it was concluded that the equipment, from a construction standpoint, was satisfactory enough for our purpose.

RESULTS

In Table 1 there are presented the results of exposing six species of insects to ten wave-length bands of equal physical intensities, in the sector type equipment. By consulting the percentage distributions of those reacting positively to the various

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[1] JOURNAL NEW YORK ENT. SOC., Vol. XLIX, p. 1–20, p. 149–159, 1941; Vol. L., p. 1–35, 1942.

TABLE 1

Name and date tested	No. tests	Total no. insects involved	Exposure minutes	Per cent in black chamber†	Per cent in introduction chamber	Per cent in centre	Per cent reacting to wave-lengths	Distribution of those reacting positively to various wave-lengths*										Relative physical intensity at introduction point
								3650 Å Per cent	4360 Å Per cent	4640 Å Per cent	4920 Å Per cent	5150 Å Per cent	5460 Å Per cent	5750 Å Per cent	6060 Å Per cent	6420 Å Per cent	7200 Å Per cent	
Diptera																		
Drosophila, Age 7 days +, 3–26–42	1	372	18	2	80	9	9	91	3	0	3	3	0	0	0	0	0	3
Drosophila, Age 3 days +, 2–16–42	1	1,464	15	2	68	27	3	79	3	5	5	3	0	3	2	0	0	3
Drosophila, Age 3 days +, 3–18–42	1	301	15	3	29	23	45	81	5	5	3	5	1	0	0	0	0	3
Drosophila, Age 4 days, 11–25–41	1	655	15	0	0	86	14	54	7	8	9	11	8	0	3	0	0	3
Drosophila, Age 8 days +, 3– 6–42	1	387	15	4	22	41	33	74	2	1	2	11	6	1	2	1	0	3
Drosophila, Age 7 days +, 10–21–41	1	154	15	3	5	33	59	56	12	7	13	10	2	0	0	0	0	3
Drosophila, Age 7 days +, 10–21–41	1	55	15	4	0	36	60	70	6	6	12	3	0	3	0	0	0	3
Drosophila, Age 7 days +, 11–24–41	1	508	15	1	2	64	33	79	5	1	5	5	1	3	0	1	0	3
Drosophila, Age 7 days +, 9–23–41	1	147	15	0	0	40	60	46	8	9	17	13	6	1	0	0	0	3
Coleoptera																		
Leptinotarsa decemlineata, 6– 3–42	2	283	25	5	5	42	48	42	21	5	15	7	5	4	1	0	0	3
Leptinotarsa decemlineata, 6– 3–42	2	401	25	6	7	39	48	21	19	9	16	13	7	7	3	4	1	3
Leptinotarsa decemlineata, 6– 4–42	1	60	25	3	22	32	43	42	8	15	27	0	0	4	0	4	0	3
Leptinotarsa decemlineata, 6– 4–42	1	156	25	2	8	45	45	34	15	9	22	7	7	1	2	2	1	3
Leptinotarsa decemlineata, 6–27–42	3	402	25	4	11	44	41	30	20	11	16	8	6	3	4	1	1	3
	2	274	20	3	6	50	41	27	14	13	16	8	9	6	2	4	1	3
Chrysochus auratus, 6–29–42	2	370	20	4	10	28	58	53	12	3	8	9	3	4	2	4	2	3
Chrysochus auratus, 6–30–42	2	361	20	10	11	35	44	53	9	3	7	9	6	1	5	3	4	3
Popillia japonica, 7–14–42	2	355	20	7	9	15	69	17	15	6	20	28	10	2	1	1	0	3
Macrobasis unicolor, 6–24–42	2	123	20	9	8	10	73	42	6	5	12	12	6	7	4	5	1	3
Blepharida rhois, 9–22–41	1	85	20	0	21	13	66	67	11	11	0	11	0	0	0	0	0	3
Popillia japonica, 7–23–42	2	405	25	8	6	20	66	19	9	10	24	18	14	2	2	1	1	3

* Angstrom units represent peak intensities of bands.

† These percentages include the relatively small numbers that entered the black chambers between the light chambers.

wave-length bands and by an examination of the group behavior curves in Figures 1, 2 and 3, it may be noted that the largest numbers of most of the species reacted positively to 3650–3663 Å (ultraviolet).

The nine different lots of *Drosophila melanogaster* behaved in a remarkably uniform pattern. This is shown graphically on Figure 1, where it may be noted that the peak response took place in the ultraviolet, with a minor secondary peak at 4920 Å (blue-blue-green) or 5150 Å (blue-green). The results of our tests do not differ qualitatively from those of Bertholf who worked with 30 wave-lengths from 2300 Å to 7000 Å, using an entirely different experimental method. Quoting from Bertholf's paper: "The results show that, starting with the longer wave-lengths the efficiency is very low until it starts to rise at about 5750 Å; from here it rises to a maximum in the so-called visible spectrum at 4870 Å . . .; from this wave-length it decreases again at 4250 Å; then it rises suddenly and attains a maximum value of 3650 Å . . .; from here it decreases rapidly to zero at 2540 Å."[2]

The group behavior of the remaining five species is shown in detail in Table 1 and graphically by Figures 2 and 3. Except for the Japanese beetle, the peak response took place in the ultraviolet (3650 Å) and secondary peaks occurred at 4920 Å (blue-blue-green) or at 5150 Å (blue-green). The Colorado potato beetles used in these tests were all overwintering adults that had emerged in the spring and were feeding and copulating.

In Table 2 and Figures 4 and 5, are shown the responses of 8 species of Coleoptera to nine spectral bands of equal physical intensities exclusive of ultraviolet. In other words the most stimulating part of the spectrum, to many insects, *i.e.,* ultraviolet, was omitted. With the exception of the Japanese beetle, the most stimulating part of this reduced spectrum for these species was either 4360 Å (violet-blue), or 4360 Å (violet-blue) and 4920 Å (blue-blue-green) both of which were approximately equal in stimulating efficiency. In addition 5150 Å (blue-green) and 5460 Å (yellow-green) attracted slightly larger numbers than usual.

[2] Bertholf, L. M. The extent of the spectrum for Drosophila and the distribution of the stimulative efficiency in it. Z. wiss. Biol., Abt. C, 18: 32–64, 1932.

TABLE 2

Name and date tested	No. tests	Total no. insects involved	Exposure minutes	Per cent in black chamber†	Per cent in introduction chamber	Per cent in centre	Per cent reacting to wave-lengths	Distribution of those reacting positively to various wave-lengths*									Relative physical intensity at introduction point
								4360 Å Per cent	4640 Å Per cent	4920 Å Per cent	5150 Å Per cent	5460 Å Per cent	5750 Å Per cent	6060 Å Per cent	6420 Å Per cent	7200 Å Per cent	
Coleoptera																	
Plagiodera versicolora, 5–28–42	1	142	15	4	32	45	19	32	3	22	11	14	3	2	11	2	3
Lina lapponica, 5–28–42	1	218	35	5	32	32	31	31	6	23	18	7	2	7	2	4	3
Macrodactylus subspinosus, 5–26–42	2	344	20	4	8	28	60	18	3	23	20	13	2	6	5	0	3
Tetraopes tetraophthalmus, 6–24–42	3	483	25	4	12	62	22	26	8	20	11	19	1	4	11	0	3
Disonycha quinquevittata, 7–10–42	1	137	20	5	15	22	58	23	6	30	16	15	2	2	2	4	3
Chrysochus auratus, 6–27–42	2	440	25	5	5	25	65	31	10	21	12	7	4	2	9	4	3
Popillia japonica, 7– 9–42	2	372	15	3	17	27	53	10	7	24	31	12	7	4	5	0	3
Popillia japonica, 7–10–42	2	279	30	4	7	24	65	12	5	26	23	17	7	4	4	2	3
Papillia japonica, 7– 8–42	3	748	30	4	13	54	29	6	9	30	26	16	6	4	2	1	3
Leptinotarsa decemlineata, 6– 9–42	1	175	50	1	17	38	44	17	5	25	14	14	8	6	9	2	3
Leptinotarsa decemlineata, 6– 2–42	3	410	15	0	14	58	28	25	6	24	17	15	8	3	2	0	3
Leptinotarsa decemlineata, 6– 4–42	3	565	25	7	11	38	44	18	10	20	11	14	5	6	12	4	3

* Angstrom units represent peak intensities of bands.

† These percentages include the relatively small numbers that entered the black chambers between the light chambers.

In fact if we combine the figures for 4920 Å, 5150 Å, and 5460 Å it will be found that in our entire spectrum the largest percentage was stimulated by wave-lengths from 4920 to 5460 Å. In the absence of ultraviolet this part of the spectrum was the most stimulating for the species tested. The peak response for the Japanese beetle in these and in former tests where ultraviolet was available took place for the most part in the region 4700–5280 Å (blue-blue-green).

The group behavior of the Colorado potato beetle to ultraviolet light of low intensity in comparison with various other colors at higher intensities is set forth in Table 3. In these tests the introductory intensity (*i.e.,* that to which the insects were first exposed), of the ultraviolet was 3 and the intensity of each of the other wave-lengths was 100. From Table 3 it may be noted that weak ultraviolet was more stimulating than wave-lengths of stronger intensities from infra-red to yellow-yellow-green, and that ultraviolet at an intensity of 3 was approximately equal in stimulating efficiency to wave-lengths from yellow-green to violet-blue at intensities of 100. These tests were made in the two-way apparatus described and figured in the third paper.[3]

In order to determine if previous behavior to a particular wave-length band influenced succeeding behavior, groups of Japanese beetles and potato beetles were placed in the introduction chamber of the sector type equipment and exposed to certain wave-length bands. After an exposure period of 20 or 30 minutes the insects that had gone to a particular filter chamber were removed and immediately exposed to 10 wave-length bands of equal physical intensities including the one to which they had previously been "conditioned."

The results of these tests with the Japanese beetles are shown in Table 4 and Figure 6. In general the behavior to the 10 wave-length bands was more or less similar to the behavior of groups that had never been previously conditioned to any particular band. Apparently the previous conditioning of the five different groups of beetles utilized in Table 4 had no influence upon their subsequent behavior pattern. Perhaps the conditioning period was too short. Perhaps the sensitivity of the iris pigment in

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[3] JOUR. N. Y. ENT. SOC., Vol. L, p. 1–35, 1942.

TABLE 3

BEHAVIOR OF THE COLORADO POTATO BEETLE TO ULTRAVIOLET LIGHT OF LOW INTENSITY IN COMPETITION WITH VARIOUS OTHER COLORS AT COMPARATIVELY HIGH INTENSITIES

No. tests	No. insects involved	Per cent not reacting	Per cent reacting	Exposure minutes	Wave-length bands (intensity 3)	Per cent reacting positively	Wave-length bands* (intensity 100)	Per cent reacting positively	Colors of light transmitted by filters in Column 8
3	289	26	74	35	3650–3663	95	7200	5	infra-red
3	243	12	88	15	3650–3663	72	6420	28	orange-red
3	500	11	89	15	3650–3663	70	6060	30	yellow-orange
3	383	12	88	15	3650–3663	64	5750	36	yellow-yellow-green
3	373	10	90	15	3650–3663	56	5460	44	yellow-green
3	414	12	88	15	3650–3663	51	5150	49	blue-green
3	439	13	87	15	3650–3663	46	4920	54	blue-blue-green
3	405	14	86	15	3650–3663	51	4640	49	blue
3	385	13	87	15	3650–3663	46	4360	54	violet-blue

* Peak of intensity of bands.

these insects was such as to result in rapid adaptation. Whatever the reason, previous conditioning as described did not result in any appreciable change in their behavior pattern.

In Table 5 and Figure 7, the results are given for a similar set of tests with the Colorado potato beetle. These results and conclusions are the same as those recorded in the preceding paragraph for the Japanese beetle.

Table 6 records the results of testing the behavior of *Drosophila melanogaster* to blue-blue-green at a fixed introductory intensity in competition with ultraviolet at varying introductory intensities. These tests were conducted in the two-way apparatus which consisted of two wooden light-tight runways emanating at right angles to each other from an introduction chamber about 8.5 inches square. (See JOUR. N. Y. ENT. SOC., Vol. L, p. 16, 1942, for description.) With this apparatus it was possible to test the insects from 1 to 11 feet away from the light chambers and consequently at different introductory intensities. The 18 tests recorded in Table 6 involved the use of over 16,000 insects. All were killed after each test so that they could be counted. Sperimens found in the runways leading to light chambers were counted as reacting positively although they had not actually reached the light chambers at the ends of the exposure periods.

According to Table 6 when ultraviolet and blue-blue-green were of equal physical intensities approximately 71 per cent of the insects went to ultraviolet. When the insects were introduced to ultraviolet at such reduced intensities as 11, 3, 1.2 and 0.8 while the blue-blue-green introductory intensity was kept at 100, their reactions were approximately unchanged. Ultraviolet at the weak introductory intensities remained about the same in stimulating efficiency. The apparent progressive increase in the percentages of insects reacting positively to ultraviolet as the introductory intensity was reduced, we do not consider significant. *Drosophila melanogaster* is temperamental. As a rule, young flies, 3 to 4 days old appeared to be less interested in light than older ones, 6 to 8 days old. And those of all ages unless they were in the right physiological or other state refused to perform and stayed in the introduction chamber. The only conclusion to be drawn from the results in Table 6 is that Drosophila in the right state is extremely photopositive to small amounts of ultraviolet.

TABLE 4

BEHAVIOR OF THE JAPANESE BEETLE TO TEN WAVE-LENGTH BANDS OR COLORS IMMEDIATELY FOLLOWING THEIR EXPOSURE TO A SINGLE BAND OR COLOR

Previously exposed for 20′ to	No. tests	Total no. insects involved	Exposure minutes	Per cent in black chamber	Per cent in introduction chamber	Per cent in centre	Per cent reacting	Distribution of those reacting positively to various wave-lengths*									
								3650 Å Per cent	4360 Å Per cent	4640 Å Per cent	4920 Å Per cent	5150 Å Per cent	5460 Å Per cent	5750 Å Per cent	6060 Å Per cent	6420 Å Per cent	7200 Å Per cent
3650–3663 Å ultra-violet	1	38	25	5	0	5	90	14	9	3	29	20	20	0	5	0	0
4120–4760 Å violet-blue	1	38	35	8	13	21	58	31	5	5	27	9	9	5	0	9	0
4700–5280 Å blue-blue-green	1	54	30	2	9	15	74	15	12	10	17	25	12	3	3	0	3
4940–5660 Å blue-green	1	63	20	5	1	19	75	32	13	8	19	11	17	0	0	0	0
5300–5760 Å yellow-green	1	40	20	0	8	35	57	17	4	0	31	22	18	4	4	0	0

* Peak intensities of bands.

TABLE 5

BEHAVIOR OF THE COLORADO POTATO BEETLE TO TEN WAVE-LENGTH BANDS OR COLORS IMMEDIATELY FOLLOWING THEIR EXPOSURE TO A SINGLE BAND OR COLOR

Previously exposed for 30′ to	No. tests	Total no. insects involved†	Exposure minutes	Per cent in black chamber	Per cent in introduction chamber	Per cent in centre	Per cent reacting	Distribution of those reacting positively to various wave-lengths*									
								3650 Å Per cent	4360 Å Per cent	4640 Å Per cent	4920 Å Per cent	5150 Å Per cent	5460 Å Per cent	5750 Å Per cent	6060 Å Per cent	6420 Å Per cent	7200 Å Per cent
4120–4760 Å violet-blue	1	74	20	3	11	47	39	10	24	7	17	20	7	14	0	0	0
3650–3663 Å ultra-violet	1	42	20	4	2	44	50	48	5	5	19	14	5	4	0	0	0
4420–5000 Å blue	1	43	20	6	12	38	44	13	27	7	33	13	7	0	0	0	0
4700–5280 Å blue-blue-green	1	48	30	6	0	42	52	20	24	8	28	8	4	0	0	4	4
Not previously exposed to any wave-lengths	1	163	45	21	6	42	31	10	6	12	37	6	4	13	4	6	2
	2	386	90	20	7	42	31	21	12	6	22	14	8	5	3	6	3

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* Peak intensities of bands.

† All tests were made during the last few days of September.

TABLE 6

BEHAVIOR OF *Drosophila melanogaster* TO BLUE-BLUE GREEN AT A FIXED INTRODUCTORY INTENSITY IN COMPETITION WITH ULTRAVIOLET AT VARYING INTRODUCTORY INTENSITIES

No. tests	No. insects involved	Per cent not reacting	Per cent reacting positively	Exposure minutes	Per cent reacting positively to 3650–3663 Å (ultraviolet)	Relative physical intensity of ultraviolet	Per cent reacting positively to 4700–5280 Å (blue-blue-green)	Relative physical intensity of blue-blue-green
4	2,386	59	41	10	71	100.0	29	100
3	2,334	63	37	20	68	11.0	32	100
3	2,961	33	67	20	84	3.0	16	100
5	5,269	46	54	20	78	1.2	22	100
3	3,296	30	70	15	86	0.8	14	100

NOTES

Photinus scintillans Say. A preliminary test of this species of "firefly" (Lampyridæ) in the sector type equipment, in which it was exposed to the ten wave-length bands used in the other tests, indicated that ultraviolet (3650 Å) was highly effective in stimulating efficiency. Owing to the small number (41) available, and these were dark adapted for one hour, it is not possible to be definite about their reactions. Their behavior to ultraviolet is interesting, however, in view of the fact that they are nocturnal and because the spectra of fireflies, which extend from about 5000 Å to 5900 Å, contain no ultraviolet or blue.

Autoserica castanea Arrow. This nocturnal species when dark adapted for 24 hours was highly sensitive to ultraviolet.

Popillia japonica Newm. Seven tests, involving 1,900 beetles, were run in the sector type equipment. The ultraviolet band (3650–3663 Å) had a relative physical intensity of 3 and the 9 remaining spectral bands, each had an intensity of 1.5. After exposures from 20 to 30 minutes, the group behavior was found to be similar to that resulting from the exposure of the Japanese beetle to 10 wave-length bands each with an intensity of 3.

In general the results of our 1942 tests were approximately the same as those for 1941, when the same experimental methods were used with different groups of the same species. Within certain limits variations in group behavior are to be expected when one considers that an insect's reaction to light is influenced by many factors, previous exposure to light, angle of incidence, variations in sensitivity of different parts of the compound eye, position of the iris pigment and the rate of pigment migration in relation to light intensity, temperature, moisture, air currents, chemotropism, its variable physiological state, the stimulation of sense organs other than the eyes, the influence of the central nervous system and the wave-length and intensity of the radiation to which it is first exposed.

PLATE V

Figure 1. Behavior of *Drosophila melanogaster* to 10 wave-length bands from 3650 Å to 7200 Å. Physical intensities equalized.

1, 34 flies (1 test), age 7 days +, dark conditioned for 18 hours before test.
2, 39 flies (1 test), age 3 days +.
3, 135 flies (1 test), age 3 days +, dark conditioned 3 hours before test.
4, 90 flies (1 test), age 4 days.
5, 128 flies (1 test), age 8 days +.
6, 91 flies (1 test), age 7 days +.
7, 33 flies (1 test), age 7 days +.
8, 170 flies (1 test), age 7 days +.
9, 87 flies (1 test), age 7 days +.

Figure 2. Behavior of Coleoptera to 10 wave-length bands from 3650 Å to 7200 Å. Physical intensities equalized.

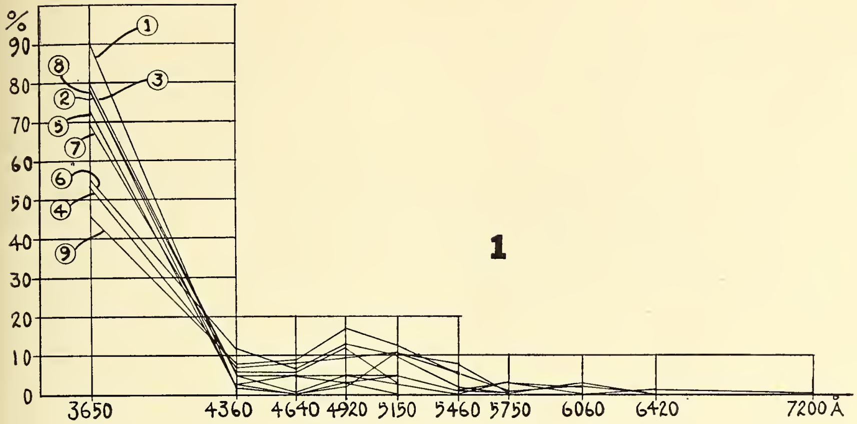
1, 163 Colorado potato beetles (3 tests).
2, 114 Colorado potato beetles (2 tests).
3, 215 *Chrysochus auratus* (2 tests).
4, 160 *Chrysochus auratus* (2 tests).
5, 245 Japanese beetles (2 tests).

Figure 3. Behavior of Coleoptera to 10 wave-length bands of equal physical intensities from 3650 Å to 7200 Å.

1, 136 Colorado potato beetles (2 tests).
2, 194 Colorado potato beetles (2 tests).
3, 26 Colorado potato beetles (1 test).
4, 69 Colorado potato beetles (1 test).
5, 90 *Macrobasis unicolor* (2 tests).

Figure 4. Behavior of Coleoptera to 9 wave-length bands from 4360 Å to 7200 Å. Physical intensities equalized.

1, 79 *Disonycha quinquevittata* (1 test).
2, 284 *Chrysochus auratus* (2 tests).
3, 197 Japanese beetles (2 tests).
4, 182 Japanese beetles (2 tests).
5, 216 Japanese beetles (3 tests).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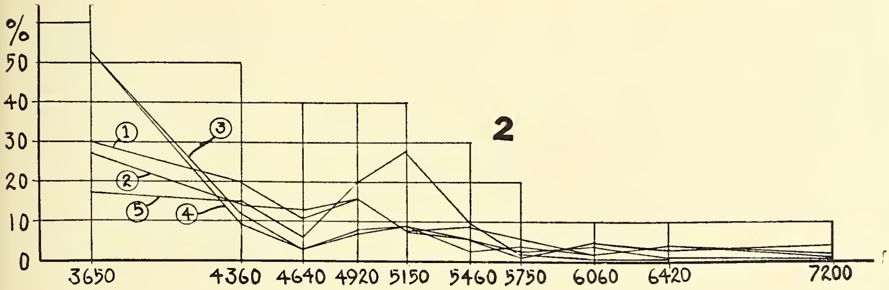
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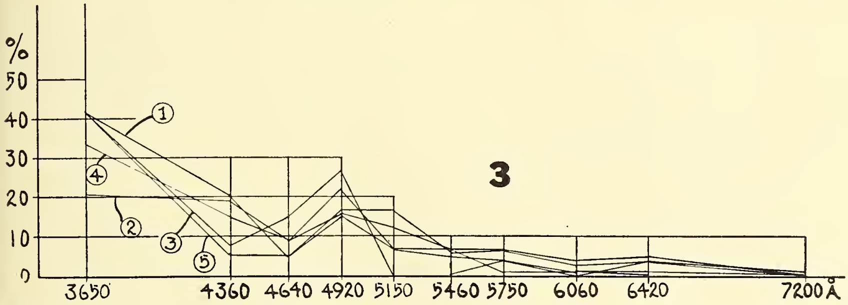
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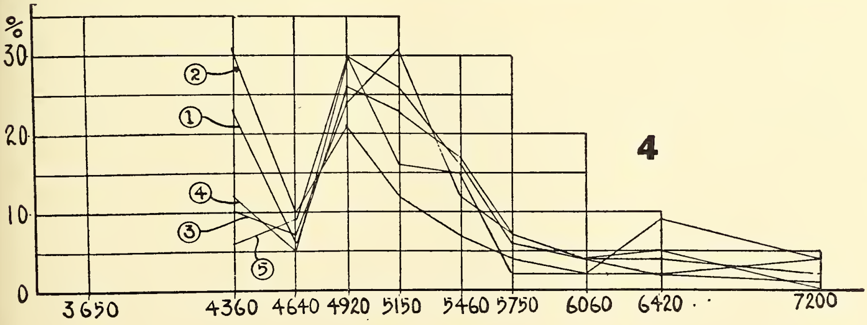
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PLATE VI

Figure 5. Behavior of Coleoptera to 9 wave-length bands from 4360 Å to 7200 Å. Physical intensities equalized.

Upper—1, 37 *Plagiodera versicolora* (1 test).
2, 69 *Lina lapponica* (1 test).
3, 205 *Macrodactylus subspinosus* (2 tests).
4, 106 *Tetraopes tetraophthalmus* (3 tests).

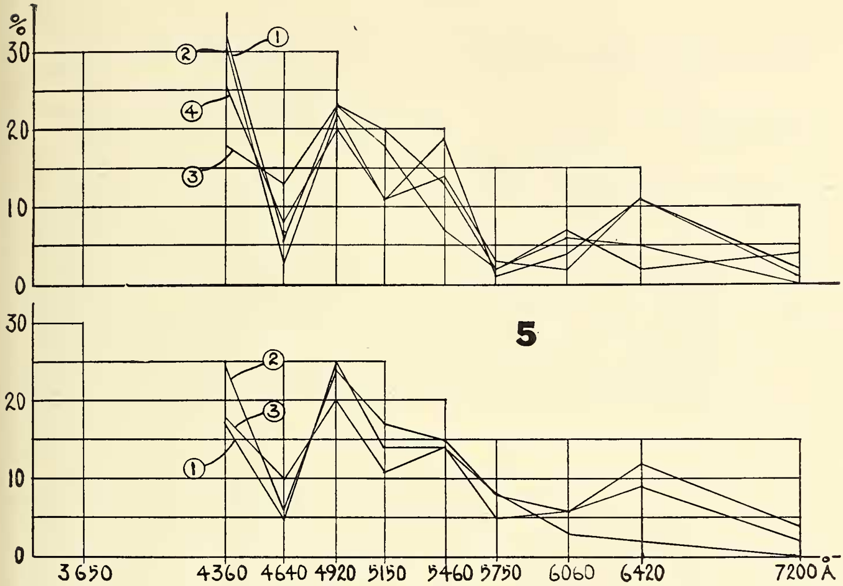
Lower—1, 76 Colorado potato beetles (1 test).
2, 114 Colorado potato beetles (3 tests).
3, 249 Colorado potato beetles (3 tests).

Figure 6. Behavior of the Japanese beetle to 10 wave-length bands of equal physical intensities from 3650 Å to 7200 Å, after having previously been exposed or "conditioned" to particular wave-lengths. Second exposure to 10 bands followed immediately the first exposure to one band.

1, Previously exposed to 3650–3663 Å, ultraviolet.
2, Previously exposed to 4120–4760 Å, violet-blue.
3, Previously exposed to 4700–5280 Å, blue-blue-green.
4, Previously exposed to 4940–5660 Å, blue-green.
5, Previously exposed to 5300–5760 Å, yellow-green.

Figure 7. Behavior of the Colorado Potato Beetle to 10 wave-length bands of equal physical intensities from 3650 Å to 7200 Å, after having previously been exposed to particular wave-lengths.

1, Previously exposed to 4120–4760 Å (violet-blue).
2, Previously exposed to 3650–3663 Å (ultraviolet).
3, Previously exposed to 4420–5000 Å (blue).
4, Previously exposed to 4700–5280 Å (blue-blue-green).
5, Behavior to 10 wave-length bands without previous exposure to any.
6, Behavior to 10 wave-length bands without previous exposure to any.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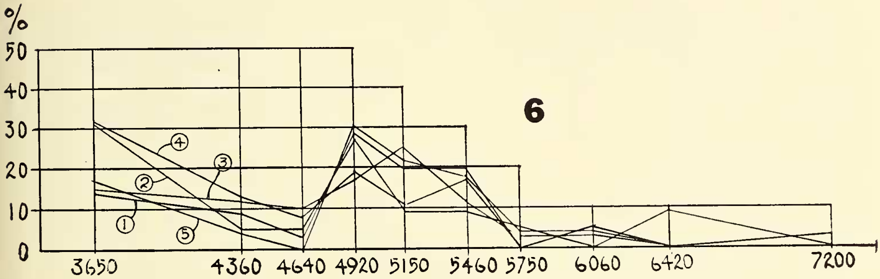
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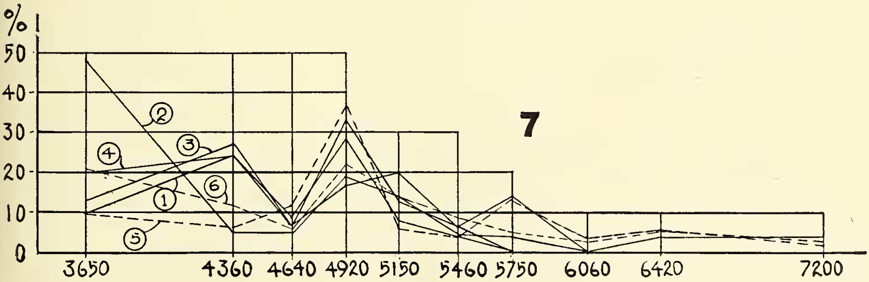
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7200

7